QUANTITATIVE PRECIPITATION FORECASTING REQUIRES KNOWLEDGE OF

- SYNOPTIC, MESOSCALE AND MICROSCALE PROCESSES
- AND MODEL PERFORMANCE IN FORECASTING THESE PROCESSES

QUESTIONS TO ASK WHEN PREPARING A QPF

- WHAT IS THE TIME RANGE AND PERIOD OF THE FORECAST?
- IS THIS SYNOPTIC OR MESOSCALE PATTERN ONE YOU RECOGNIZE?
- WHAT TYPE PRECIPITATION EVENT AM I DEALING WITH, CONVECTIVE OR STRATOFORM? OR SOME COMBINATION OF BOTH?
  - DOES THIS PATTERN FAVOR HEAVY OR LIGHT RAINFALL
- HOW CONFIDENT ARE YOU OF YOUR FORECAST?
  - IF YOU LACK CONFIDENCE, BE CONSERVATIVE

THE AMOUNT OF RAINFALL THAT FALLS OVER AN AREA DEPENDS ON

- SIZE OF THE RAINFALL AREA
- THE INTENSITY OF THE RAINFALL WITHIN IT
- HOW FAST THESE AREAS MOVE
- HOW FAST NEW RAIN BEARING CLOUDS ARE FORMING UPSTREAM (PROPAGATION)

A FEW IDEAS TO HELP DETERMINE HOW BIG AN AREA OF RAINFALL TO FORECAST

- THE SIZE IS DEPENDENT ON HOW MUCH MOISTURE IS PRESENT AND ON THE STRENGTH OF THE MOISTURE TRANSPORT
- THE SIZE IS ALSO DEPENDENT ON HOW MUCH MOISTURE IS PRESENT
  - IS DEPENDENT ON BOTH THE ABSOLUTE (PWS, MIXING RATIOS) AND RELATIVE MOISTURE (RH)
- THE SIZE IS DEPENDENT ON THE SYSTEMS MOVEMENT
- PATTERN RECOGNITION IS ONE OF THE BEST TOOLS TO USE WHEN TRYING TO FORECAST THE SCALE OF THE EVENT.
- MODEL GUIDANCE PROVIDES A FIRST GUESS ESPECIALLY OF COOL SEASON STRATOFORM EVENTS

PATTERN RECOGNITION IS VERY, VERY IMPORTANT

- PATTERNS VARY BY
  - SEASON, GEOGRAPHIC REGION AND SCALE
- PATTERNS ARE IDENTIFIED
  - BY CONVENTIONAL DATA, MODEL OUTPUT, SATELLITE AND RADAR IMAGERY
- HEAVY RAINFALL EVENTS SHARE CERTAIN CHARACTERISTICS
  - EVEN IN WINTER, HEAVY RAIN USUALLY FALLS IN MESOSCALE BANDS
- HEAVY RAINFALL EVENTS CAN OFTEN BE IDENTIFIED BY THEIR PATTERNS
  - BUT YOU NEED TO UNDERSTAND WHAT IT IS ABOUT THE PATTERN THAT FAVORS HEAVY RAINFALL

START BY LOOKING AT SYNOPTIC SCALE (THE BIG PICTURE)

- THERE IS A CLEAR ASSOCIATION BETWEEN SHORT-WAVE TROUGHS AND CONVECTION
- THE VERTICAL MOTION ASSOCIATED WITH SYNOPTIC SCALE LIFT DOES NOT TYPICALLY ALLOW PARCELS TO REACH THE LEVEL OF FREE CONVECTION (LFC)
- HOWEVER, LARGE SCALE LIFT
  - STEEPENS LAPSE RATE
  - PROMOTES MOISTURE TRANSPORT
  - WEAKENS CAP
  - AFFECTS VERTICAL SHEAR (more important for severe weather forecasting)

NEXT LOOK FOR MESOSCALE FEATURES

– DO A MESOANALYSIS OF SURFACE AND UPPER AIR DATA IS TIME ALLOWS.
– LOOK AT SATELLITE AND RADAR AND TRY TO IDENTIFY MESOSCALE FEATURES. ALSO TRY TO DETERMINE WHAT IS CAUSING THE CURRENT PRECIPITATION.
– IDENTIFY SURFACE BOUNDARIES
  - (FRONTS, DRY LINES, OUTFLOW BOUNDARIES, SEA BREEZE FRONTS, LAND USE BOUNDARIES, ETC.

USE MODELS TO IDENTIFY SYNOPTIC AND MESOSCALE PATTERNS THAT ARE FAVORABLE TO HEAVY RAINS

- CAN USE THE SURFACE, 850- AND 500-MB PATTERNS TO IDENTIFY MADDOX ET AL. OR OTHER TYPES OF HEAVY RAIFALL
  - ALSO NEED TO LOOK CLOSELY AT MOISTURE AND MOISTURE TRANSPORT
- MODELS PROVIDE DECENT FORECASTS OF LOW-LEVEL WIND AND MOISTURE FIELDS
  - 850 MOISTURE TRANSPORT
  - PWS
- OUTPUT CAN BE USED TO ASSESS FORCING AND TO FORECAST THE LOCATION OF BOUNDARIES
      - BEWARE OF MODEL BIASES!!

PRECIPITATION INTENSITY

- IS PROPORTIONAL TO THE VERTICAL MOISTURE FLUX.
  - THEREFORE, FORECASTS SHOULD START WITH AN ASSESSMENT OF HOW MUCH MOISTURE WILL BE AVAILABLE
  - NEED TO ESTIMATE WHAT PROPORTION OF THE MOISTURE ENTERING THE CLOUD SYSTEM WILL FALL AS RAIN (THE EFFICIENCY OF THE SYSTEM)
  - NEED TO ASSESS THE LIFTING
    - ARE MESOSCALE SOURCES OF LIFT PRESENT?
    - HOW MUCH POTENTIAL BUOYANT ENERGY IS PRESENT?

PRECIPITATION EFFICIENCY FACTORS

- WANT A DEEP WARM LAYER
  - RAINFALL INTENSITY WILL BE GREATER IF DEPTH OF WARM LAYER FROM LCL TO 0^{o}C ISOTHERM IS 3-4 KM.
  - LOW CLOUD BASE (USUALLY OCCURS WITH HIGHER RELATIVE HUMIDITIES)
- COLLISION-COALESCENCE PROCESSES ARE ENHANCED BY INCREASED RESIDENCE TIME IN CLOUD
- WANT A BROAD SPECTRUM OF CLOUD DROPLET SIZES
  - ***THIS IS PRESENT WHEN AIRMASSES HAVE HAD LONG TRAJECTORIES OVER OCEANS.***
- WEAK TO MODERATE SHEAR

BECAUSE THE VERTICAL TRANSPORT OF MOISTURE HELPS DETERMINE PRECIPITATION RATES

- ASSESSING THE LIFTING IS EXTREMELY IMPORTANT.
- REMEMBER TO LOOK FOR--
  - SYNOPTIC SCALE LIFTING
  - MESOSCALE SOURCES OF LIFTING (USUALLY IS STRONGER THAN SYNOPTIC SCALE LIFTING
  - CONDITIONAL SYMMETRIC INSTABILITY (CSI)
  - CAPE (BOUYANT ENERGY)

MORE ON PRECIPITATION EFFICIENCY OF A SYSTEM

- SOME OF INFLOWING WATER VAPOR PASSES THROUGH THE SYSTEM WITHOUT CONDENSING
- OF THE VAPOR THAT CONDENSES
  - SOME EVAPORATES
  - SOME FALLS AS PRECIPITATION
  - SOME IS CARRIED AWAY AS CLOUDS (PERHAPS EVAPORATING SOMEWHERE ELSE)
- IN DEEP CONVECTION, MOST OF THE INPUT CONDENSES

FROM DOSWELL NOTES, 1995

EVAPORATION IS A FUNCTION OF

- ENVIRONMENTAL HUMIDITY
  - THE HIGHER THE RH THE LESS EVAPORATION.
- MICROPHYSICAL EFFECTS
  - WHETHER DROPLETS OR ICE CRYSTALS
- ENTRAINMENT

Will convection occur

- convection produces most heavy rainfall events
- there are three ingredients needed for deep moist convection
  - moisture
  - instability
  - upward motion

ASSESSING INSTABILITY

- SOUNDINGS ARE BEST TOOL, LOOK FOR
  - DEPTH OF MOISTURE
  - VERTICAL WIND PROFILE
  - CAPE AND CIN
  - EQUILIBRIUM LEVEL (WARM TOP CONVECTION)
- STABILITY INDICES (LIFTED, K, TOTALS, SHOWALTER)
  - K INDICES ARE A GOOD INDICATOR OF THE DEPTH OF THE MOISTURE

ANTICIPATE HOW THE STABILITY IS CHANGING

- THE LAPSE RATE CAN BE CHANGED BY
  - DIABATIC HEATING
  - ADVECTION OF A DIFFERENT LAPSE RATE INTO THE AREA
  - DIFFERENTIAL ADVECTION OF TEMPERATURE
  - VERTICAL MOTION/DIFFERENTIAL VERTICAL MOTION

CAPE

- THE POSITIVE AREA OF THE SOUNDING BETWEEN THE LFC AND EQUILIBRIUM LEVEL
- THEORETICAL MAXIMUM VALUE OF VERTICAL MOTION =$(2CAPE)^{1/2}$
- CAPE IS A BETTER INDICATOR OF INSTABIITY THAN ANY INDEX THAT USES ONLY MANDATORY LEVELS
- WHILE INSTABILITY IS PRESENT WITH ALMOST ALL HEAVY RAINFALL EVENTS, HIGH CAPES ARE NOT NEEDED FOR HEAVY RAINS
- MODELS OFTEN DON'T FORECAST CAPE WELL

TO RELEASE CONVECTIVE AVAILABLE POTENTIAL ENERGY

- SYNOPTIC SCALE FORCING DOES NOT ACT QUICKLY ENOUGH
  - BUT DOES ACT TO MOISTEN THE AIRMASS AND WEAKEN THE CAP
- YOU NEED MESOSCALE SOURCE OF LIFTING TO REACH LEVEL OF FREE CONVECTION.
  - LOW-LEVEL BOUNDARIES, FRONTS
    - LOW LEVEL CONVERGENCE
    - TRY TO FIND BOUNDARIES IN TEMPERATURE, DEWPOINT, THETA-E AND WIND FIELDS

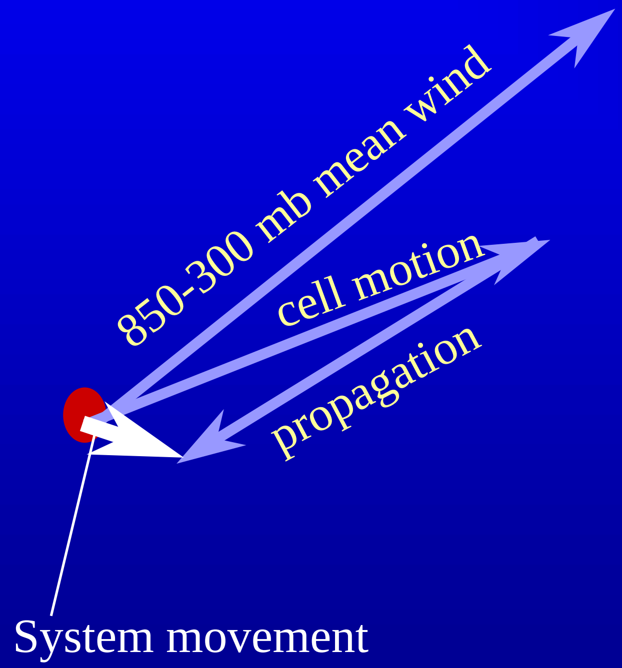
IMPORTANCE OF CIN
THE NEGATIVE AREA OF THE SOUNDING

- EARLY IN DAY SOUNDING OFTEN HAS INVERSION
- WHEN A STEEP LAPSE RATE IS LOCATED ABOVE INVERSION, YOU HAVE CLASSIC LOAD GUN SOUNDING
- THE CAP HELPS STORE ENERGY LEADING TO HIGHER POTENTIAL BUOYANT ENERGY LATER IN THE DAY OR EVENING
- BLUESTEIN AND JAIN (1985) HAVE SUGGESTED THAT SLIGHTLY STRONGER CIN UPSTREAM MIGHT SOMETIMES LEAD TO BACKBUILDING CONVECTION

MOVEMENT OF THE SYSTEM

- SLOW MOVING SYSTEMS ARE USUALLY THE HEAVIEST RAINFALL PRODUCERS
- AT SHORTER TIME RANGES-EXTRAPOLATION BASED ON RADAR AND SATELLITE PROVIDES PRIMARY GUIDANCE
- AT LONGER RANGES, MODELS PROVIDE DECENT GUIDANCE
  - YOU STILL NEED TO TAKE INTO ACCOUNT MODEL CHARACTERISTICS AND BIASES.
- AT ALL TIME RANGES, YOU MUST ANTICIPATE WHEN NEW ACTIVITY MAY FORM UPSTREAM

Movement of a system is dependent on cell movement and propagation

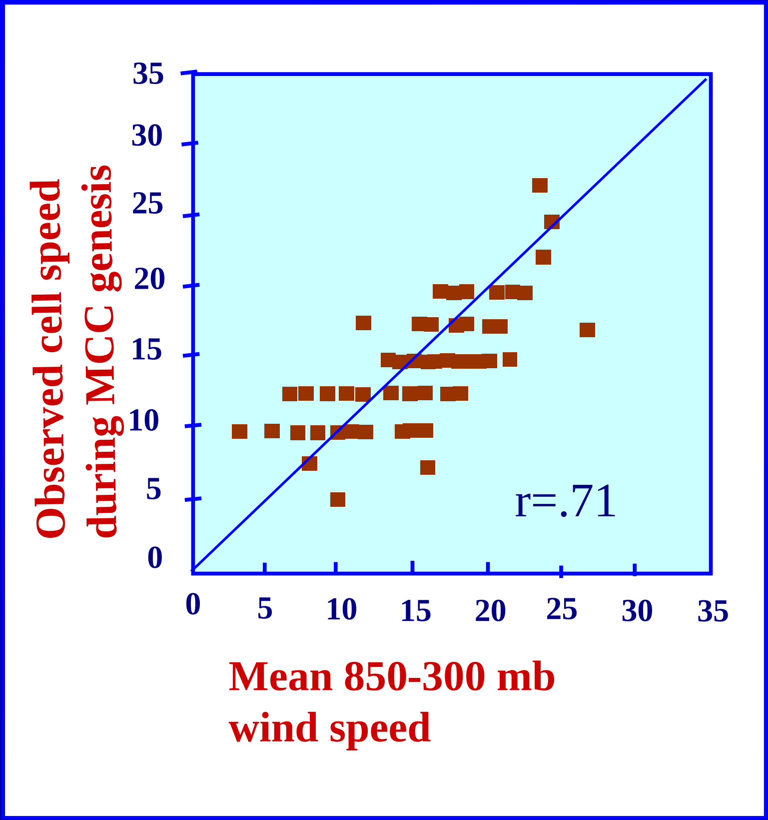


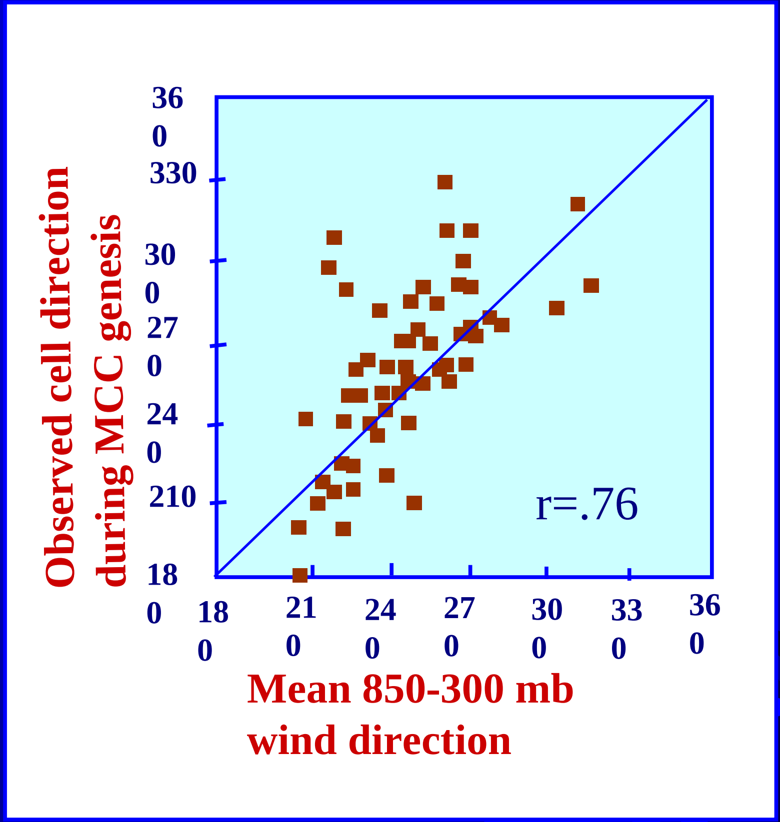
- Individual convective cells usually move at around 90% of the mean wind with a slight deviation to the right
- Propagation is dependent on how fast new cells form along some flank of the system

PROPOGATION IS ALSO DEPENDENT ON

- OUTFLOW
  - EVAPORATIONAL COOLING RELATED TO THE ENVIRONMENTAL HUMIDITY
  - GUST FRONT SPEED RELATED TO TEMPERATURE DEFICIT BETWEEN OUTFLOW AND AIR AROUND IT.
- HON-HYDROSTATIC PRESSURE GRADIENTS
  - INTERACTION OF UPDRAFT WITH ENVIRONMENTAL WIND
- STORM RELATIVE WINDS
  - DETERMINES WHERE LOW LEVEL CONVERGENCE WILL BE LOCATED.

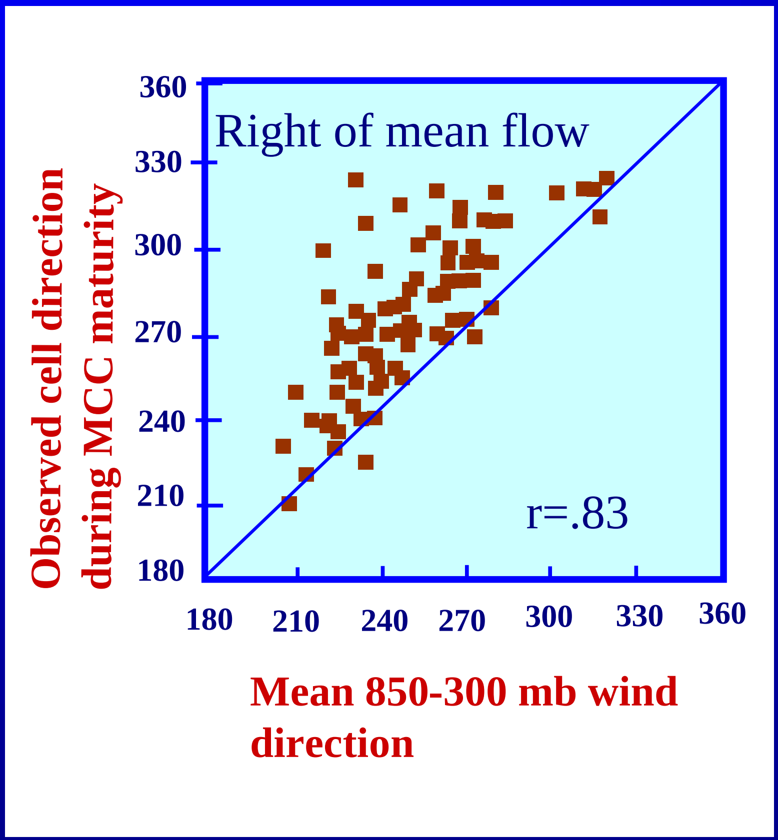
Individual cells move approximately with the 850-300 mean wind during early stages of MCSs

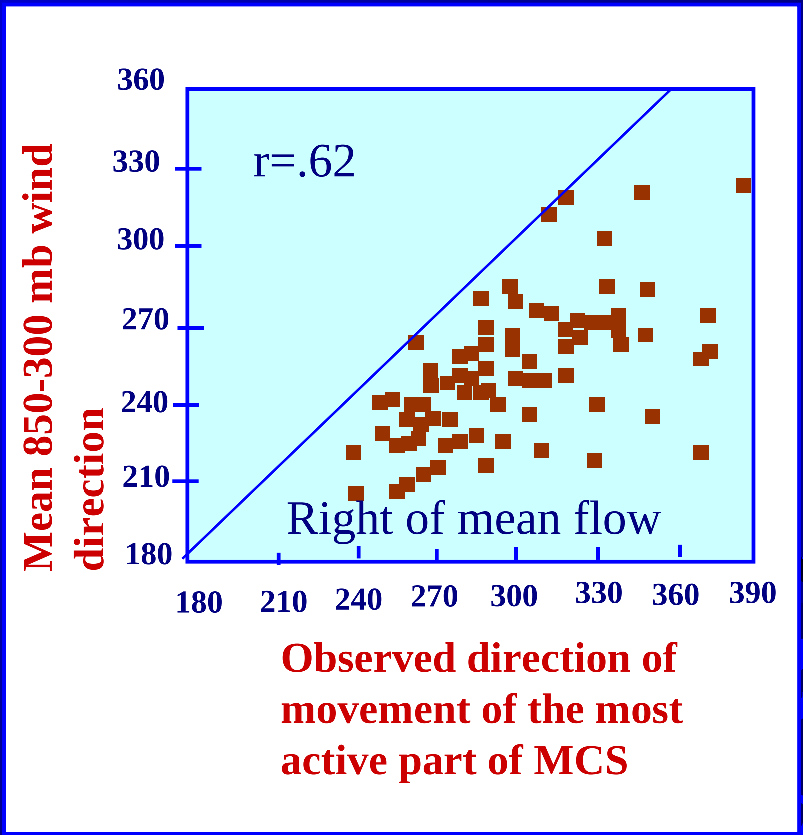




From Corfidi

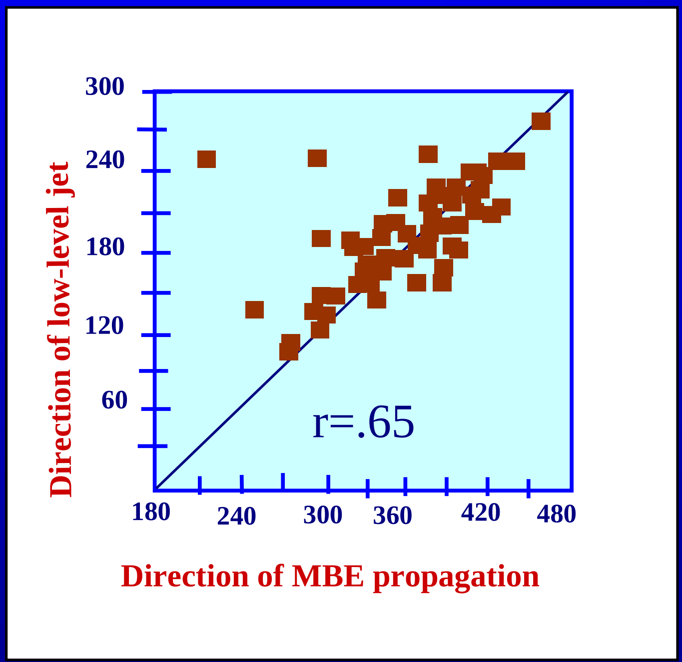
During maturity, cells apparently move towards the right. The active part of MCCs move to the right of the mean flow.





From Corfidi

The direction of the MBE (the most active part of the MCS) is dependent on the direction of the low-level jet (Corfidi et al., 1997) and on the position of the most moist and unstable air relative to the MCS.



The direction of propagation is in the opposite direction of the low-level jet. This may be why MCCs tend to track to the right of the mean wind.

Systems with propagation vectors between 0-120 degrees have been plotted between 360 and 480 degrees

From Corfidi

The CFM vector technique for predicting MCS movement

- Assumes the motion of individual cells is described by the 850-300 mean wind:

$$V_{cell} = \frac{V_{850mb} + V_{700mb} + V_{500mb} + V_{300mb}}{4}$$

- Assumes the vector describing the propagation is the vector anti-parallel to the low-level jet

$$V_{prop} = -V_{llj}$$

- If the above are true, then the vector that describes the movement of the most active part of an MCS is represented by:

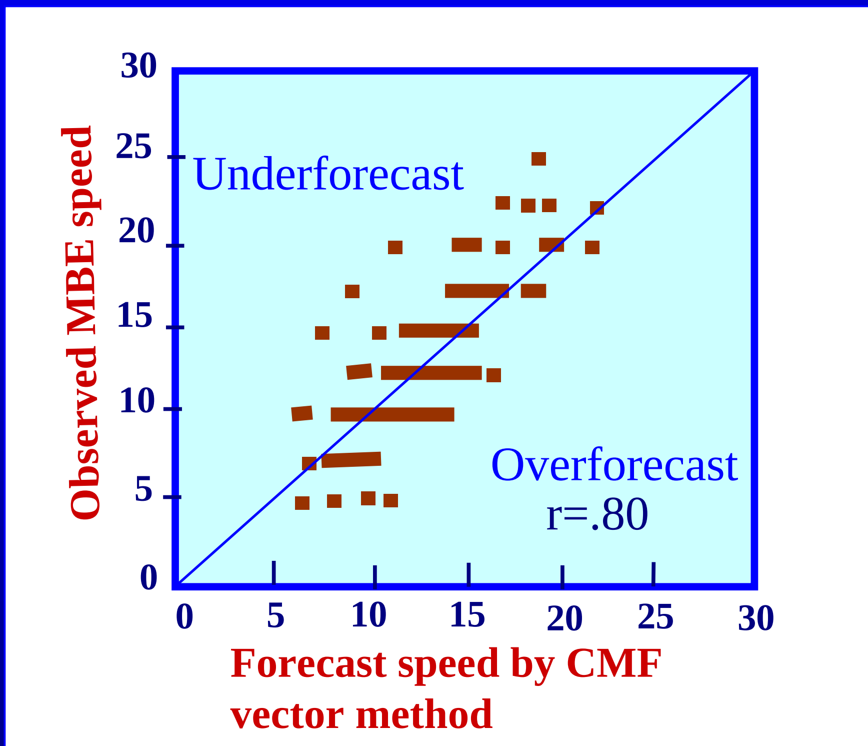
$$V_{MBE\ movement} = V_{cell} - V_{llj}$$

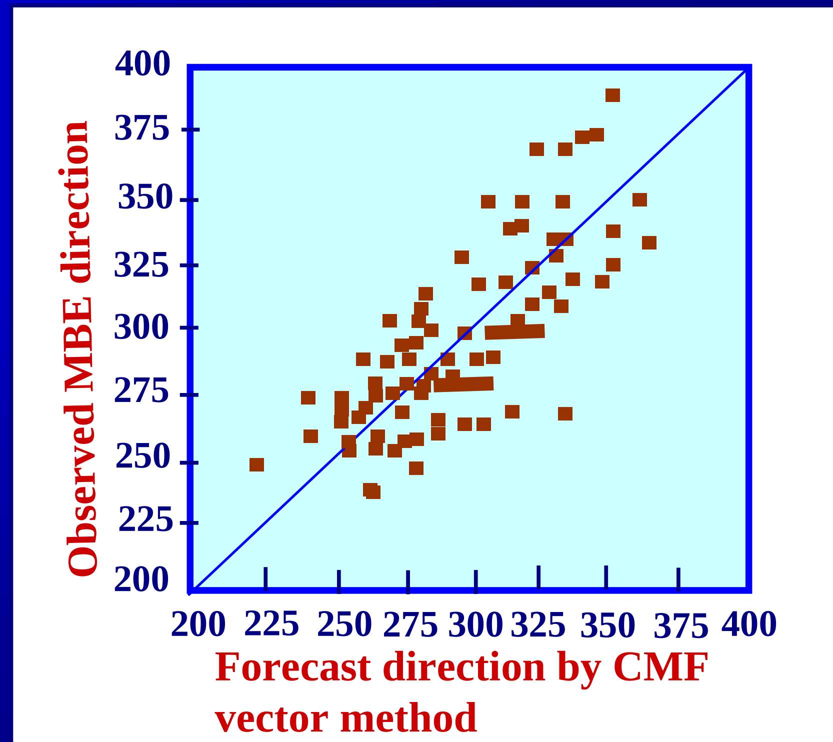
From Corfidi et al.

When applied to Merritt's data set, the technique gave good results

Caution! The low-level jet can differ significantly from the 850 mb wind.

The technique also has problems when the low-level wind field is changing rapidly



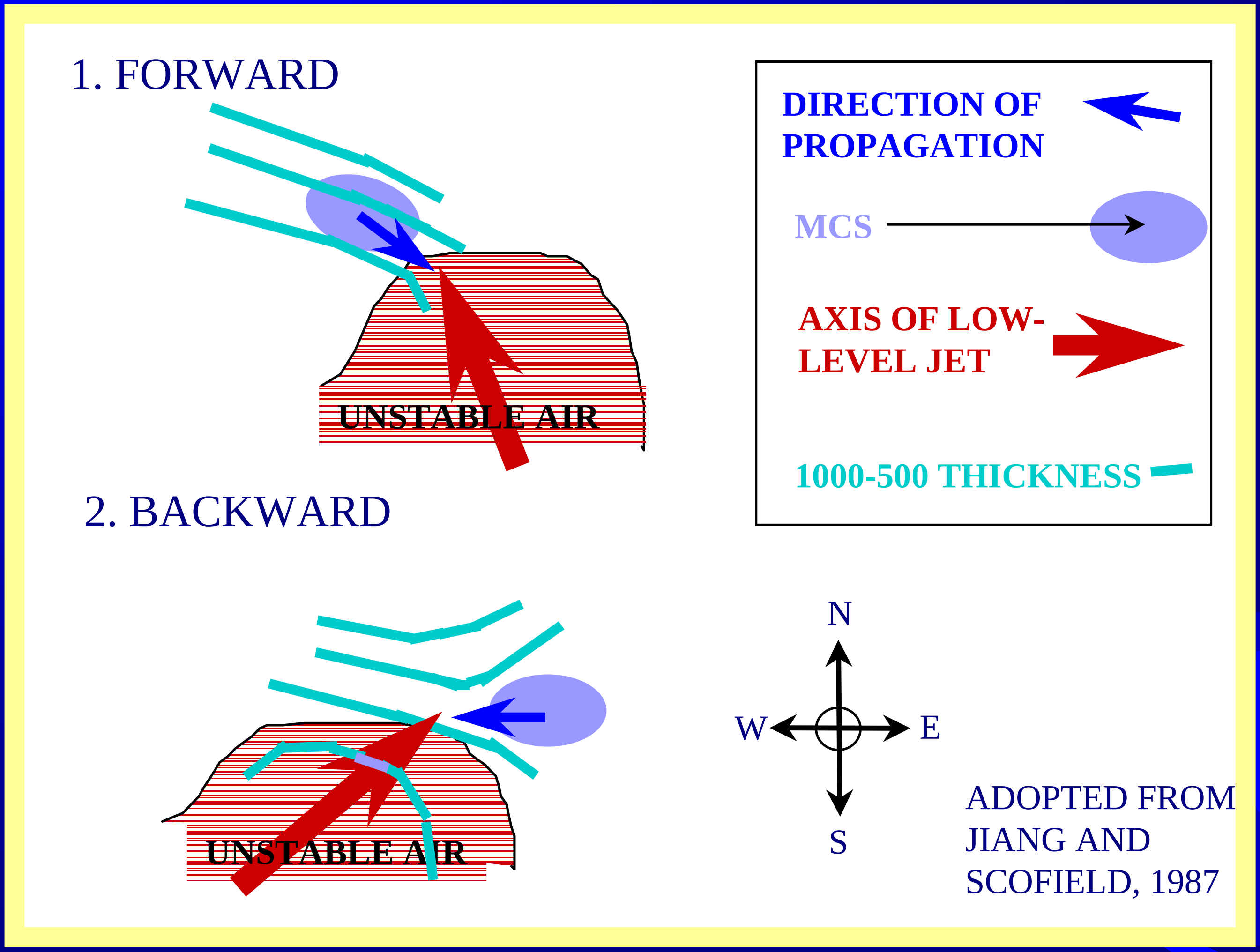


CAN USE MODEL GRIDDED WIND FIELDS TO GET PROJECTED MCS MOVEMENT VECTORS

Movement of convection and convective systems

- Individual cells movement can be approximated using the mean wind
- When storm rotate, they start to deviate from the mean flow (usually to the right)
- Movement of MCSs is dependent on, 1) the mean flow between 850-300 mb (Corfidi, 1994), and 2) the rate new cells are growing (propagation)
- The propagation rate is strongly dependent on the low-level jet but is also dependent on the strength of the cold pool
- The stronger the low-level jet (compared to the mean wind), the more the MCS will deviate from the mean wind.

THE PROPAGATION OF A CONVECTIVE SYSTEM IS DEPENDENT ON THE LOCATION OF: 1) THE MOST UNSTABLE AIR, 2) THE AXIS AND ORIENTATION OF THE LOW-LEVEL JET, AND 3) THE LOCATION OF THE STRONGEST LOW-LEVEL MOISTURE CONVERGENCE



THICKNESS CONSIDERATIONS

- MCCS OFTEN TRACK ALONG THE 1000-500 MB THICKNESS LINES
- THE AMOUNT OF MOISTURE NEEDED TO PRODUCE A LARGER SCALE MCS OR MCC APPEARS TO BE DEPENDENT ON THE 1000-500 THICKNESS
- RAINFALL OFTEN OCCURS ALONG A FAVORED THICKNESS CHANNEL
- WATCH FOR MCC DEVELOPMENT AND HEAVY RAIN IN AREAS OF DIFLUENT THICKNESS

An example of a quasi-stationary convective system

The most unstable air is usually found upstream of the initial convection during backbuilding or quasi-stationary convective events

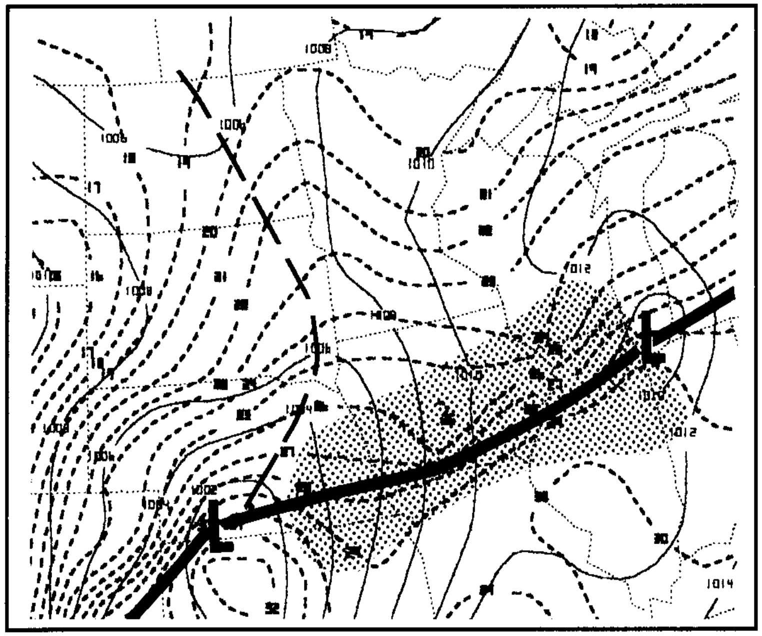


Fig. 4. RDAS mean sea-level pressure (solid lines, every 2 mb), 982 sigma level temperatures (dashed, every 1°C), precipitable water (values equal or greater than 1.80 in. shaded), front (thick line) and trough (dashed line) valid at 0000 UTC 9 July 1993.

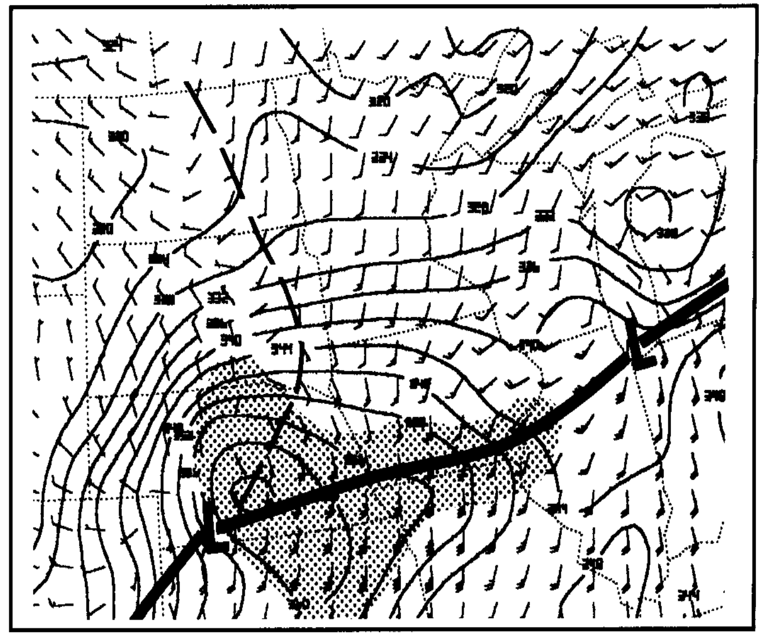


Fig. 5. RDAS 850-mb winds (full barb = 10 kt and half barb = 5 kt), equivalent potential temperature (solid, every 4° K), lifted index (values less than −8 shaded), front (thick line) and surface trough (dashed) valid at 0000 UTC 9 July 1993.

An almost e-w frontal band with PWS 1.80” or higher (shaded)

Area with most unstable Lifted Indices shaded. 35 TO 40 kt winds are feeding across KS into NE

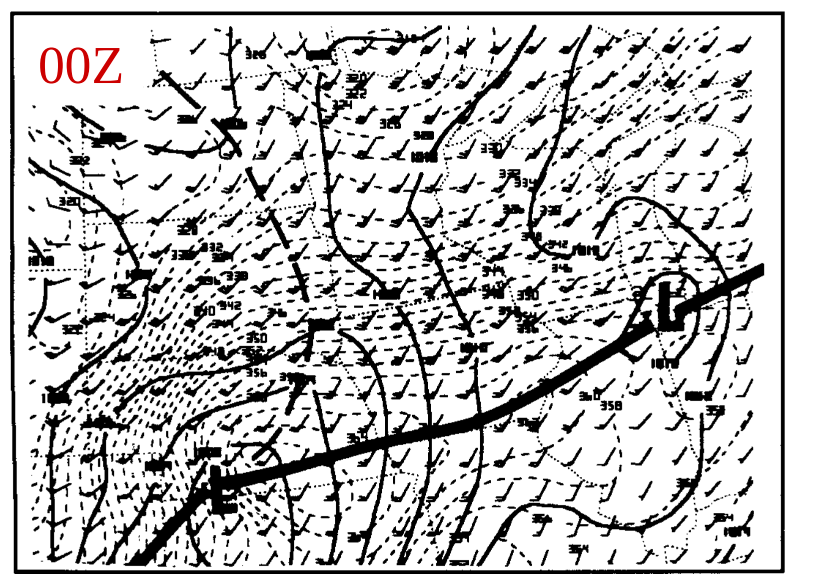
JUNKER AND SCNEIDER, 1997, *NAT. WEA. DIGEST*, **,21**, 5-17

Factors favorable to quasi-stationary convection

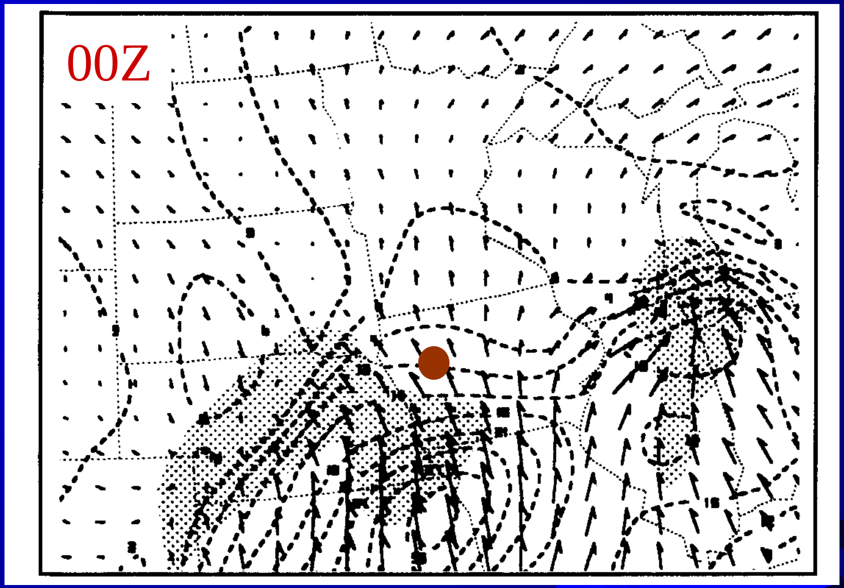
1) mean winds that are directed slightly away from the front,

2) a low-level Θ_e ridge to west, and

3) the location of the strongest moisture convergence west of the initial convection



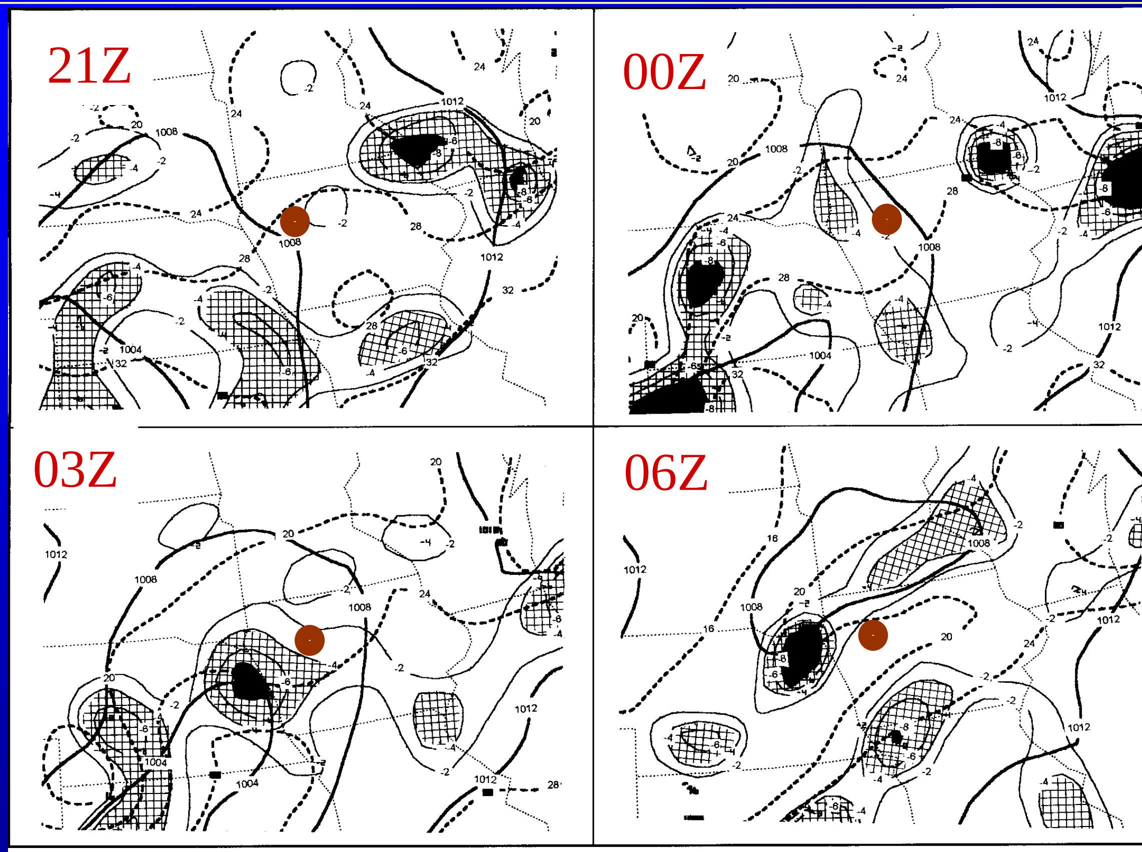
850-300 mb mean winds, 982 mb equivalent potential temperature (dashed) and msl pressure (solid)



1000-850 mb layer mean moisture flux (vectors)moisture flux magnitude (dashed) and moisture flux divergence (-4 $x10^{-7}s^{-1}$ are shaded), the red dot represents the location where convection started

JUNKER AND SCNEIDER, 1997, *NAT. WEA. DIGEST*, ,**21**, 5-17

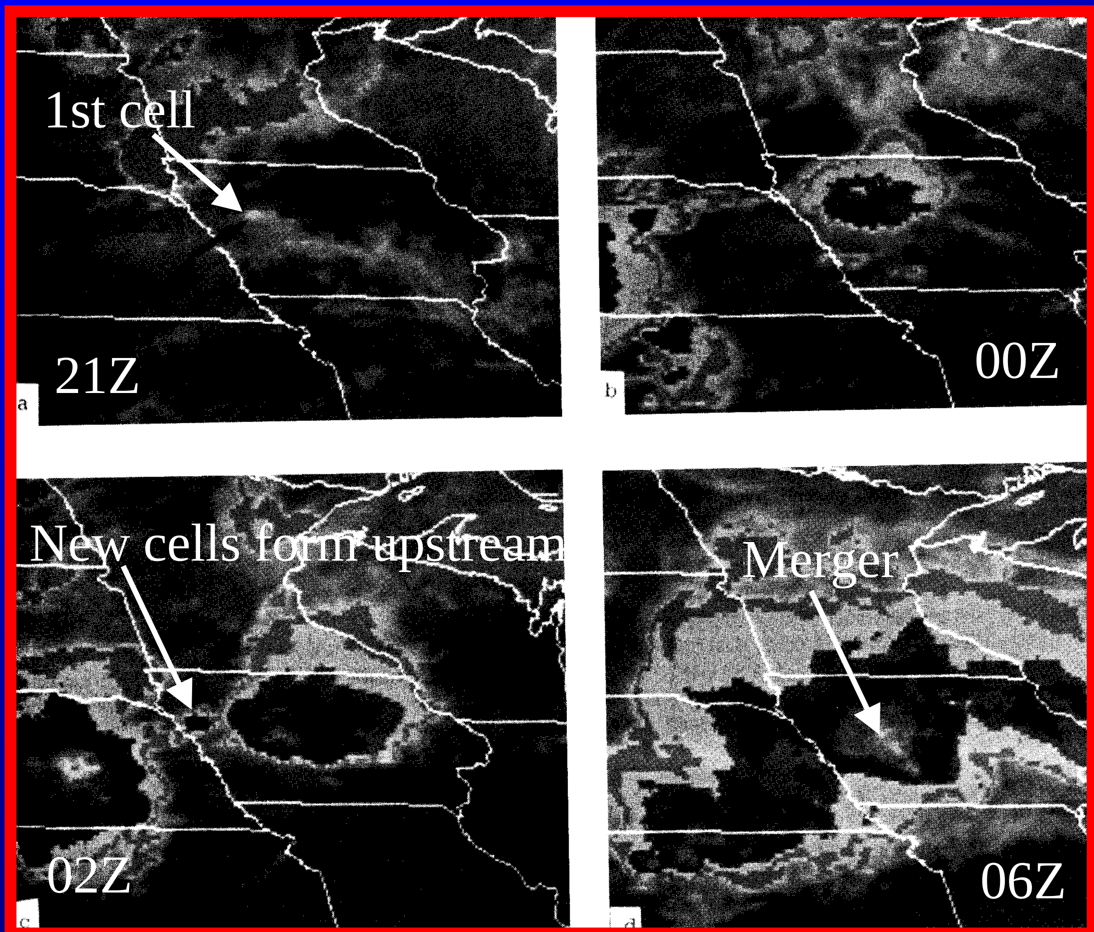
MOISTURE CONVERGENCE STRENGTHENS OVER EASTERN NE AS PRESSURES FALL IN RESPONSE TO THE APPROACH OF A WEAK SURFACE WAVE

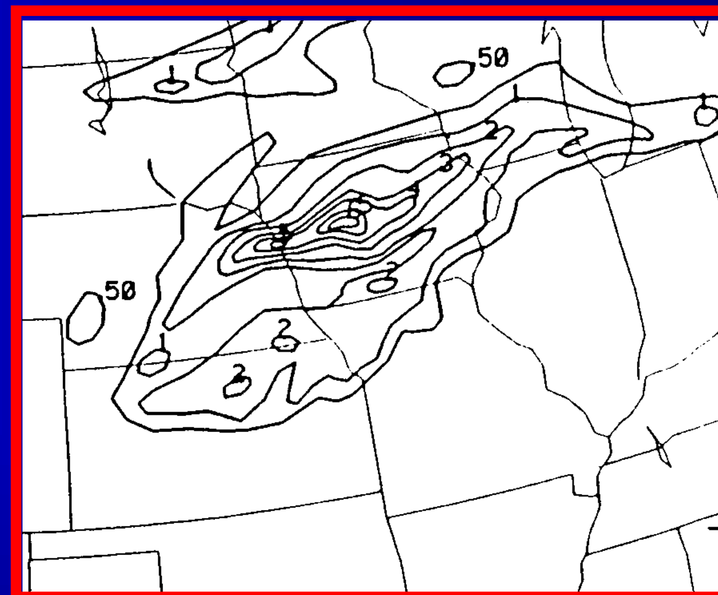


MSL PRESSURE (THICK SOLID), MOISTURE CONVERGENCE (HIGHEST VALUES SHADED), RED DOT IS WHERE INITIAL CELL FORMED

THE WIND AND MOISTURE CONVERGENCE FIELDS CAN CHANGE RAPIDLY AS A RESULT OF PRESSURE RISES OR FALLS. THE CORFIDI VECTOR METHOD MAY NOT CATCH RAPID CHANGES IN THE WIND FIELD.

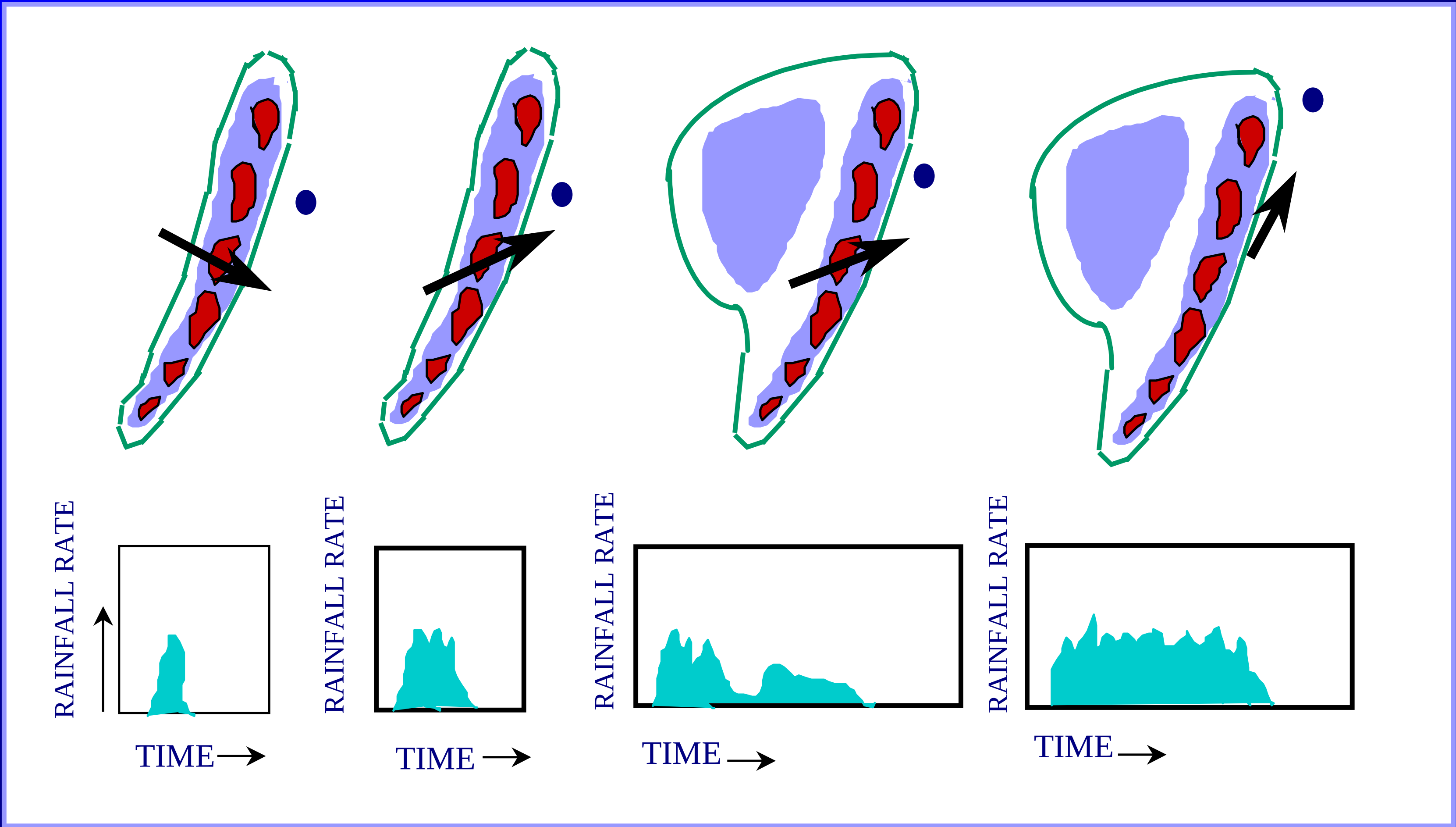
DURING THE 1993 DSM FLASH FLOOD, THE CONVECTIVE SYSTEM REMAINED STATIONARY FOR ABOUT 9 HOURS, WHY?





Accumulated precipitation from the storm

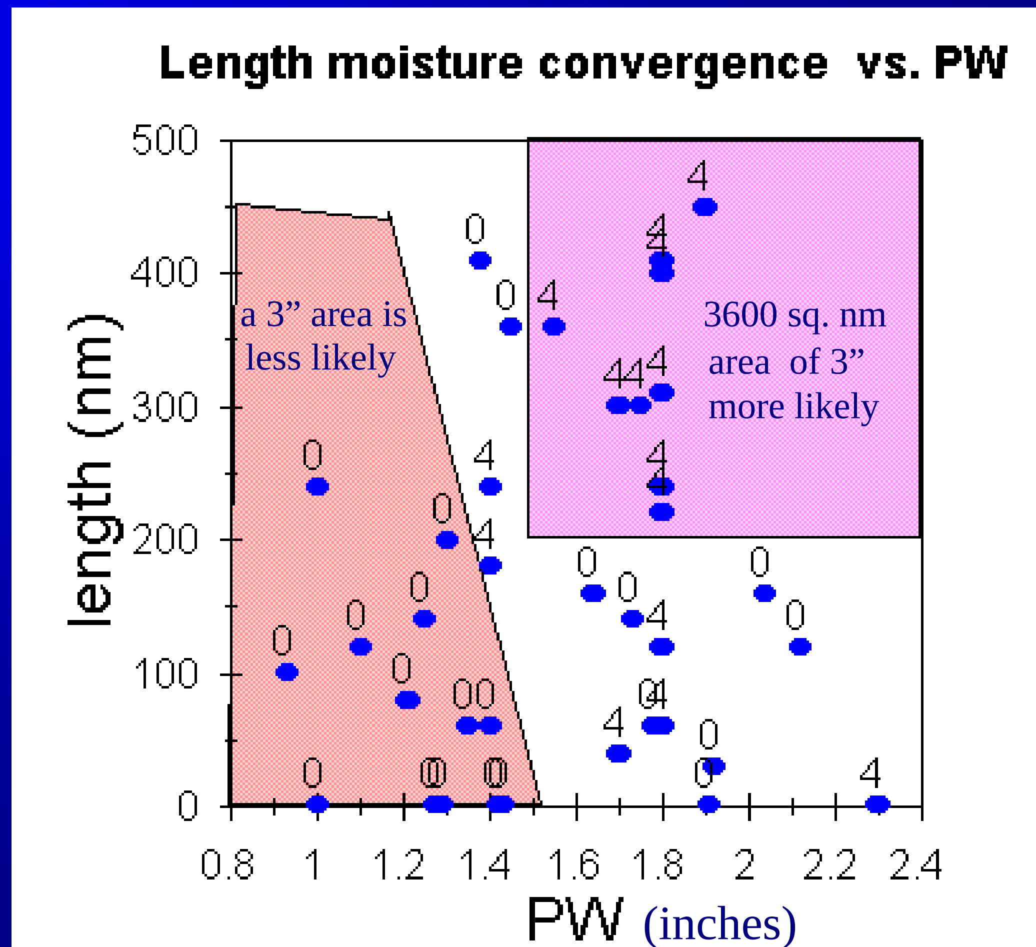
Schematic representing the affect the shape and movement of a system has on the rainfall at a particular point. The shaded colors on the system represent the radar echoes.



From Doswell et al., 1996 (*Wea. Forecasting*, **11**, 560-581)

When the moisture convergence is aligned with the 850-300 mb mean flow, a sizeable area of 3” precipitation is more likely.

THE Y-AXIS REPRESENTS THE LENGTH OF THE - $2X10^{-7}$ S^{-1} OR GREATER MOISTURE FLUX CONVERGENCE MEASURED UPSTREAM ALONG A LINE DEFINED BY THE MEAN FLOW.



FACTORS THAT LEAD TO TRAINING OR REGENERATION OF CONVECTION

- A SLOW MOVING LOW-LEVEL BOUNDARY OR FRONT
- A QUASI-STATIONARY LOW-LEVEL JET
- A QUASI-STATIONARY AREA OF UPPER-LEVEL DIVERGENCE
- A LOW-LEVEL BOUNDARY (MOISTURE CONVERGENCE) ALMOST PARALLEL TO THE MEAN FLOW
- LACK OF STRONG VERTICAL SHEAR

SHORT RANGE (0-6 HR) FORECASTS

- RELY PRIMARILY ON CURRENT OBSERVATIONS AND TRENDS
  - NEXRAD AND SATELLITE IMAGERY ARE GREAT TOOLS PROVIDING INFORMATION ON THE , SIZE AND INTENSITY AND MOVEMENT OF PRECIPITATION SYSTEMS
  - HAVE TO KNOW LIMITATIONS OF OBSERVING SYSTEMS
  - STILL HAVE TO ANTICIPATE NON-LINEAR CHANGES
    - NEW CELLS FORMING UPSTREAM

RADAR IS A GREAT TOOL FOR MAKING SHORT RANGE FORECASTS

- NEXRAD SUPPLIES ESTIMATES OF RAINFALL RATES, ACCUMULATIONS
  - HIGH TEMPORAL AND SPACIAL RESOLUTION
  - RADAR SUPPLIES ESTIMATES BETWEEN RAIN GUAGES.
- YOU CAN LOOP IMAGES TO SEE
  - CELL/SYSTEM MOVEMENT
  - WHETHER CELLS ARE TRAINING
- DESPITE STRENGTHS, KNOW LIMITATIONS

A SIMPLE STRATEGY WHEN USING NEXRAD

- KNOW MAXIMUM THRESHOLD REFLECTIVITY
- ESTABLISH VIL OF DAY, OR USE IMPROVED HAIL ALGORITHM TO DETERMINE WHETHER HAIL IS PRESENT
- WHEN HAIL IS NOT INDICATED, THEN IF OBSERVED REFLECTIVITY EXCEEEDS THE MAXIMUM THRESHOLD REFLECTIVITY, THEN
  - THE RAINFALL RATE IS PROBABLY HIGHER THAN 4” PER HOUR.

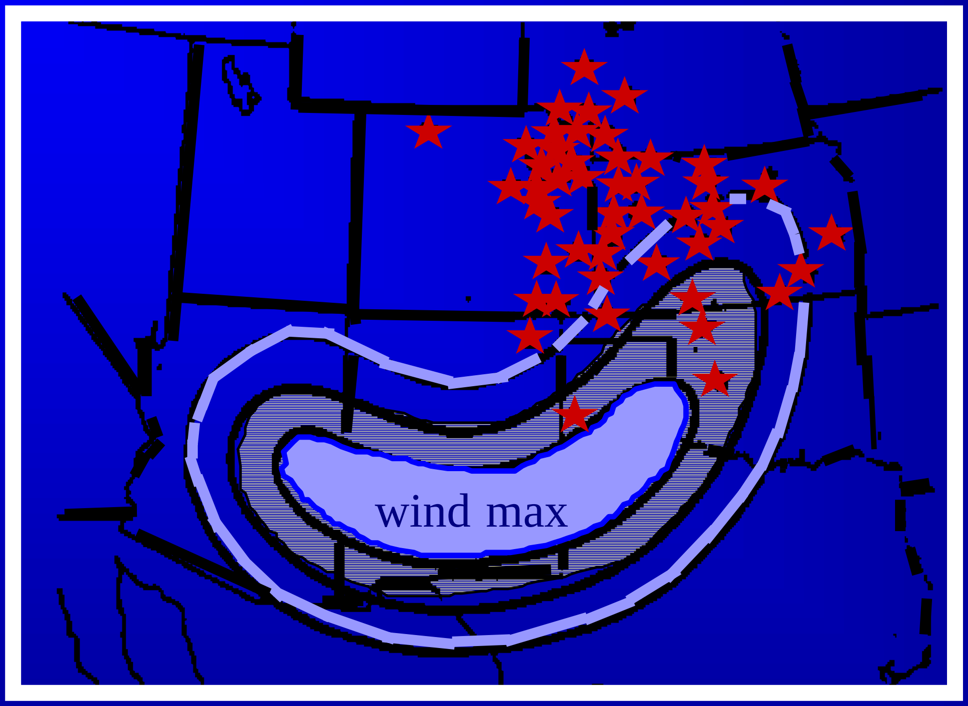
LIMITATIONS OF THE THE NEXRAD ESTIMATES

- BEAM MAY OVERSHOOT MAXIMUM REFLECTIVITY
- BEAM BLOCKAGE
- BRIGHT BANDING AND HAIL CONTAMINATION
- THE MAXIMUM THRESHOLD REFLECTIVITY (USUALLY 53 dBZ)
- VARIATION OF Z-R RELATIONSHIPS
  - DEPENDENT ON DROPLET SIZE AND DISTRIBUTION
    - BEWARE OF TROPICAL AIRMASSES

HOW THE UPPER LEVEL JET AFFECTS WEATHER SYSTEMS

- JET STEAKS HAVE BEEN ASSOCIATED WITH
  - VARIATIONS IN STRENGTH OF THE LOW-LEVEL JET
  - CYCLOGENESIS AND MAJOR SNOWSTORMS
  - FRONTOGENESIS
- REMEMBER CURVATURE AND CHANGES IN THE WIND SPEED ARE BOTH IMPORTANT

THE UPPER LEVEL JET AND CYCLONES



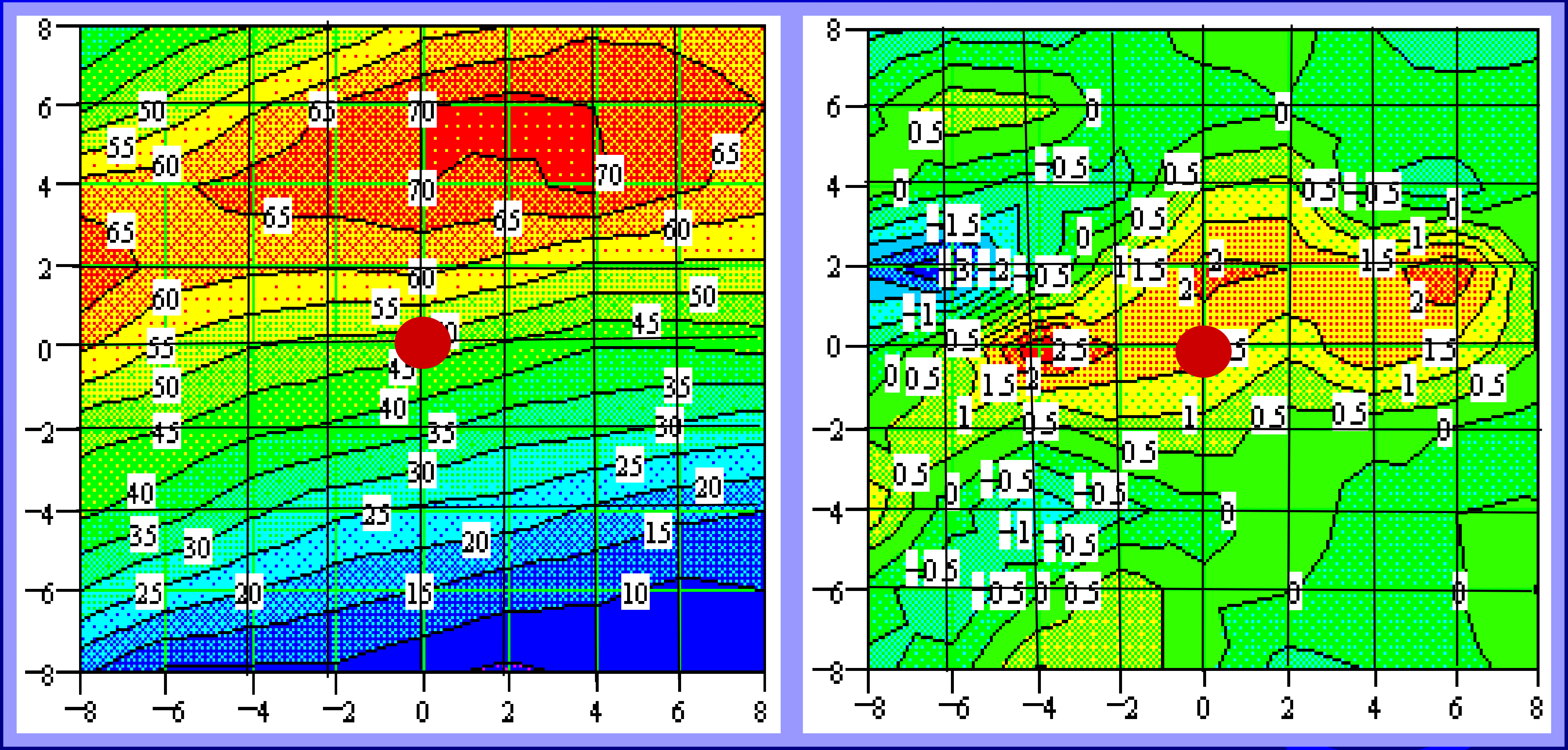
- THE STARS REPRESENT WHERE CYCLONES DEVELOPED. THE LINES ARE 250 MB ISOTACHS

JET STREAKS AND CYCLOGENESIS

- MOST LOWS TO THE LEE OF NORTH-SOUTH MOUNTAIN RANGES FORM ALONG THE LEFT EXIT REGION OF A STREAK
- THE LOW LEVEL JET IS ENHANCED DUE TO THE ISALLOBARIC WINDS ASSOCIATED WITH THE PRESSURE FALLS
- THE LOW LEVEL WINDS ALSO STRENGTHEN IN RESPONSE TO THE INCREASE IN PRESSURE GRADIENT
- THE DIFFERENTIAL TEMPERATURE AND MOISTURE ADVECTIONS ACT TO DESTABILIZE THE AIR MASS

DURING THE SUMMER OF 1993

250 mb isotachs (left) and divergence (right). The heaviest rainfall was usually located at the southern edge of the divergence.



IMPORTANCE OF THE LOW LEVEL JET

- SPEED CONVERGENCE IS MAXIMIZED AT THE NOSE OF THE JET, CONFLUENT LOW FLOW IS OFTEN PRESENT ALONG AXIS OF LLJ
- THE VERTICAL FLUX OF MOISTURE IS OFTEN RELATED TO THE STRENGTH OF THE LOW LEVEL JET (LLJ)
- DIFFERENTIAL MOISTURE AND TEMPERATURE ADVECTION CAN LEAD TO RAPID DESTABILIZATION
- A QUASI-STATIONARY LLJ SUPPORTS THE REGENERATION OF CELLS AND/OR TRAINING OF CELLS
- THE LLJ IS OFTEN LOCATED ON THE SOUTHWEST OF WESTERN FLANK OF A BACKWARD-PROPAGATING MCS.

THE LOW LEVEL JET (IN PLAINS)

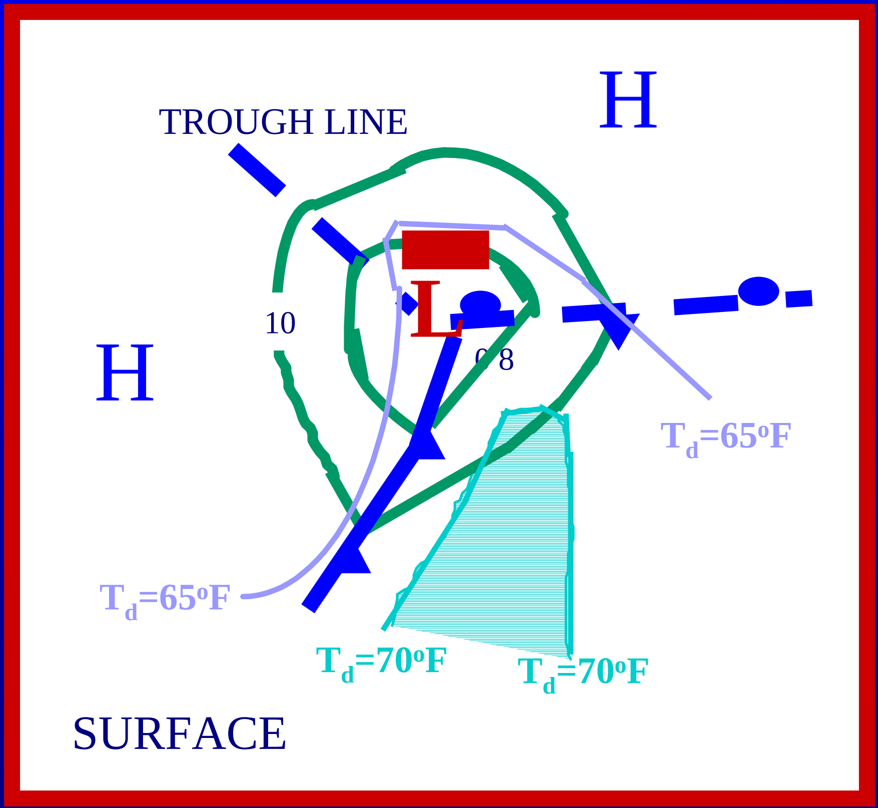
- NOCTURNAL BOUNDARY LAYER MAXIMUM
  - INERTIAL OSCILLATION CONVECTIVELY INDUCED JETLETS
- DEVELOPS IN RESPONSE TO LEE LOW DEVELOPMENT
- LOW LEVEL JET CAN BE ENHANCED BY UPPER LEVEL JET STREAK
- BARRIER JETS

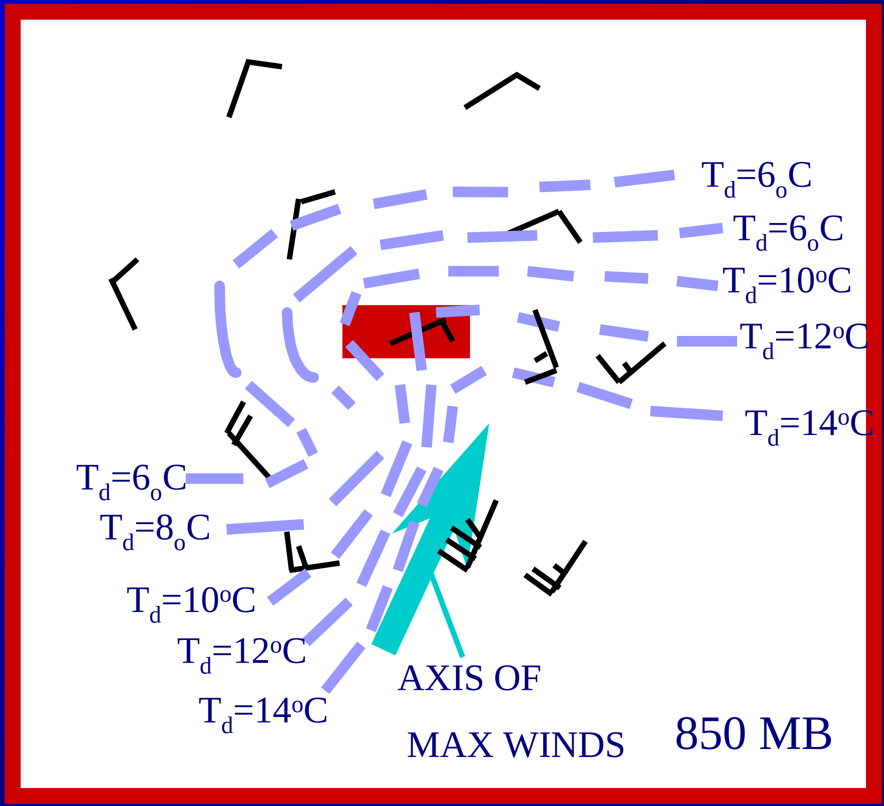
CYCLONIC CIRCULATION SYSTEMS

1. Usually associated with warm top convection

2. occur north or northeast of the surface low in the cooler air

3. occur with a weak but strengthening surface low



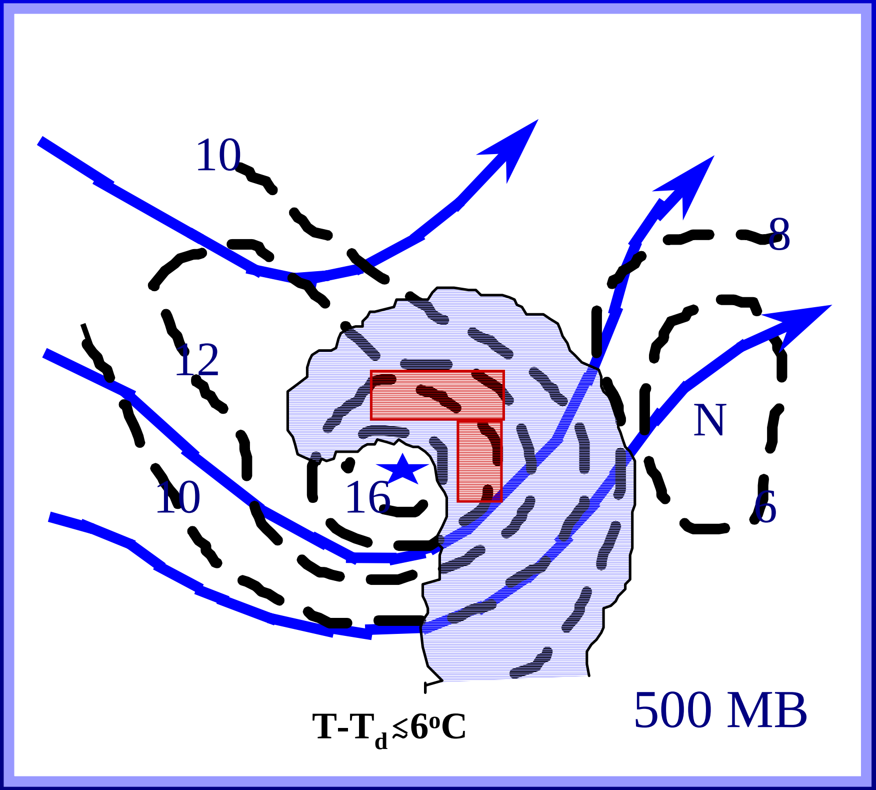


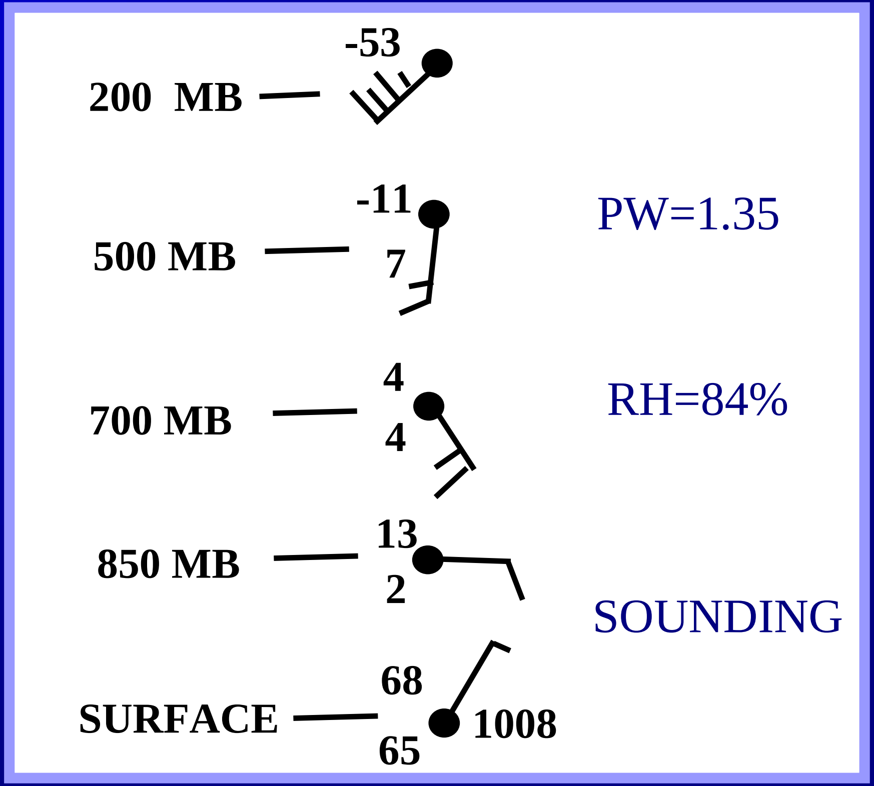
Subtle heavy rainfall events (SHARS)

4) strong vort max, usually round shaped

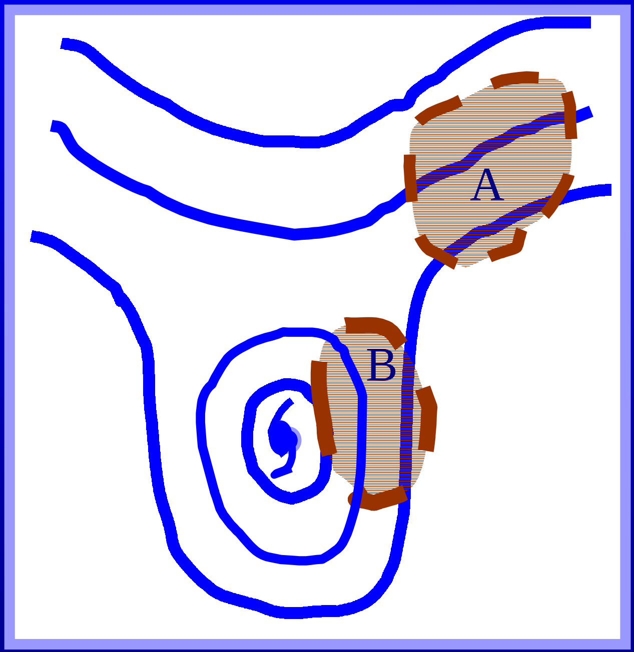
5) often the vort is strenghtening with a shortening half-wavelength

6) Beware of weak upper lows in a moist environment!





Tropical Storm Conceptual Model



Region A: the rainfall maximum along the front north of the system where the tropical moisture interacts with the westerly flow. The maximum is usually along or north of the frontal boundary and may be along the right entrance region of a jet streak

Region B: the other principal area of heavy rainfall associated with Agnes. One heavy area is usually located slightly to the right of the track of the storm.

From Bosart and Carr, 1978

Rainfall with tropical systems

- Max rainfall =100/storm speed (old rule of thumb)
- amounts of pre-existing moisture is important in governing rainfall potential
- as system makes landfall, max rainfall is usually located along the region of max inflow just to the east of the center.
- As the storm decays, heaviest precipitation often shifts to northwest side of storm especially if it is interacting with westerlies
- watch for nightime “core” rains near center; center may be deceptively inactive during the day.
- Tropical moisture associated with storm sometimes interacts with fronts north and east of the system (event if the system is hundreds of miles away.
- Pacific systems moving northeastward from Mexico can cause heavy rains well ahead of the center (can focus on a front in the Southern Plains.

RULES OF THUMB FOR PREDICTING HEAVY RAIN

- THE MAXIMUM RAINFALL USUALLY OCCURS WHERE THE CENTER OF THE STRONGEST INFLOW INTERSECTS A BOUNDARY
- THE RAINFALL MAXIMUM USUALLY OCCURS JUST NORTHEAST OF THE THETAE RIDGE
- IN SUMMER, THE HEAVIEST RAINFALL OFTEN OCCURS ALONG OUTFLOW BOUNDARIES SOUTH OF THE WARM FRONT

RULES OF THUMB CONTINUED

- INVERTED ISOBARS ALONG A FRONT CAN SIGNAL HEAVY RAINFALL POTENTIAL
- HEAVY RAIN OFTEN FALLS IN AN AREA OF THICKNESS DIFLUENCE
- BEWARE OF THICKNESS LINES WHICH HOLD STEADY OR SINK SOUTHWARD IN LOW LEVEL SOUTHERLY FLOW
- HEAVY RAINFALL SOMETIMES FALLS IN A PREFERRED THICKNESS CHANNEL

RULES OF THUMB CONTINUED

- MCSs TRACK ALONG OF SLIGHTLY TO THE RIGHT OF THE 1000-500 THICKNESS LINES
- LOOK FOR CONVECTION ALONG THE SOUTHERN EDGE OF THE WESTERLIES
- MCCs OFTEN FORM NEAR THE UPPER LEVEL RIDGE AXIS WHERE THERE IS WEAK INERTIAL STABILITY
- WATCH FOR HEAVY CONVECTION BEHIND A VORTICITY MAXIMUM OR NEAR A VORTICITY MINIMUM WHEN STRONG THERMAL AND MOISTURE ADVECTION IS PRESENT

MORE RULES OF THUMB

- A FAVORABLE JET STRUCTURE CAN ENHANCE THE HEAVY RAIN POTENTIAL
- K INDICES ARE A GOOD MEASURE OF DEEP MOISTURE, BEWARE OF K INDICES IN THE UPPER 30S
- THE MAXIMUM RAINFALL IS USUALLY WITH THE TROPICAL CORE OF A TROPICAL SYSTEM AT NIGHT, RATHER THAN THE DAYTIME PERIPHERAL ACTIVITY
- BEWARD OF TROPICAL CONNECTIONS AS OBSERVED FROM WATER VAPOR IMAGERY

MORE RULES OF THUMB

- BEWARE OF SLOW MOVING SYNOPTIC CIRCULATION (SHARS) EVENTS, THEY OFTEN HAVE WARM CLOUD TOPS
- STRONG HEIGHT FALLS AND/OR FAST MOVING SYSTEMS USUALLY PRECLUDE VERY HEAVY RAINFALL, INSTEAD THEY PRODUCE A LARGE AREA OF MORE MODEST RAINFALL (AN INCH OR TWO)
- NUMERICAL MODELS USUALLY DON'T PREDICT THE AXIS OF HEAVIEST RAINFALL FAR ENOUGH SOUTH (OUTFLOW BOUNDARIES)
- THE NGM RARELY PREDICTS OVER 3 INCHES OF RAIN
- HEAVY RAINS IN